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California Institute of Technology

New Design Paradigms Workshop
Pasadena, CA

New Horizons in
Systems Engineering

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Topics

- A few definitions
- The past
- The present
- The future
- A few conclusions

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A Few Definitions

- **System**
  - **A collection of hardware, software, people, facilities, and procedures organized to accomplish some common objectives -** ***IEEE***
  - **A construct or collection of different elements that together produce results not obtainable by the elements alone. …The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationships among the parts; that is, how they are interconnected. - E. Rechtin,** ***Systems Architecting of Organizations, 1999***

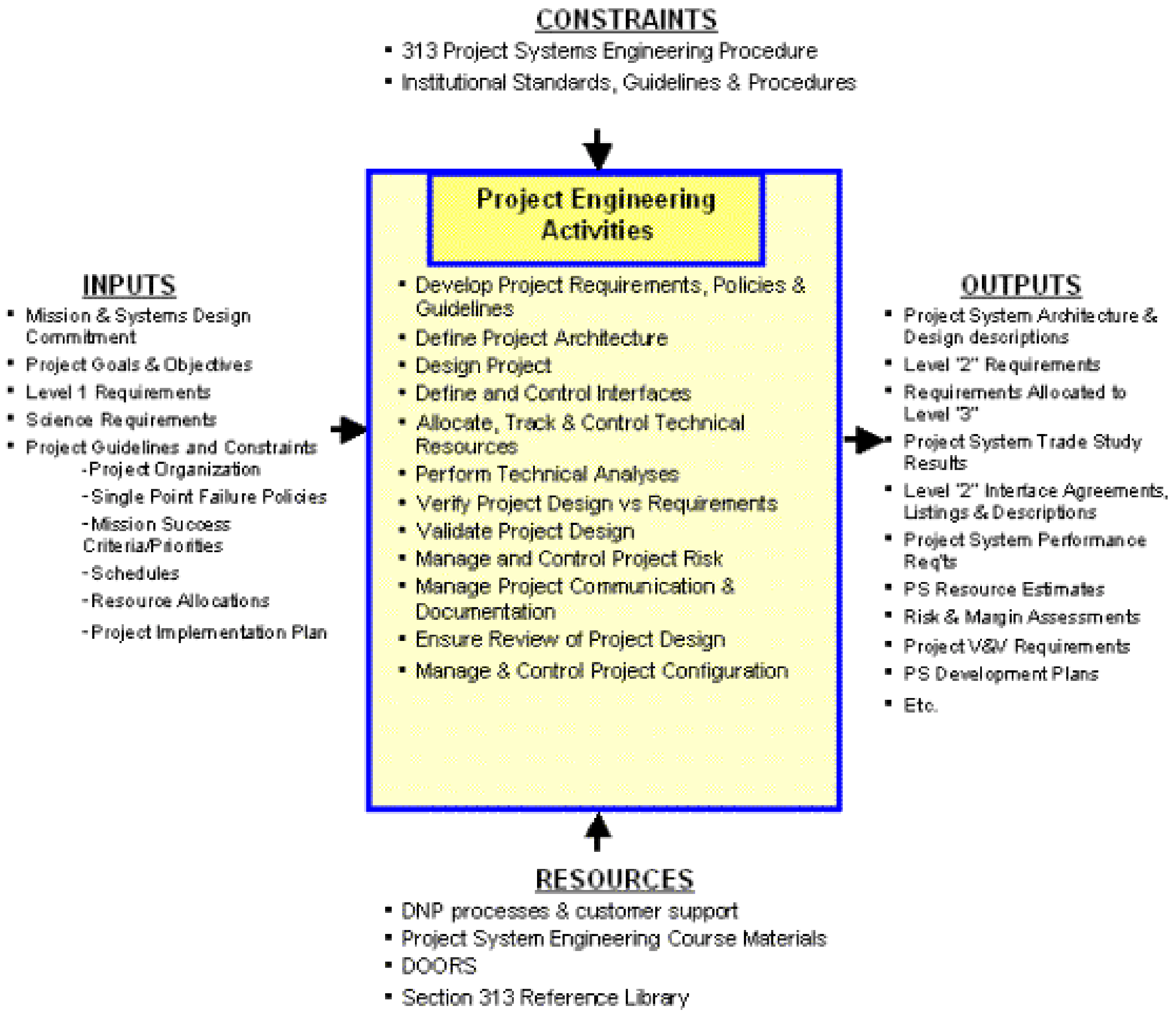
A Few Definitions

- **System Engineering**
  - **The process by which the design of a complex, multi-element system is technically coordinated and optimally matched, with constraints to the requirements on the system. In practice, System Engineering also assures that the delivered system is verified. -** ***System Engineering at JPL***
- **Architecting**
  - **Generally synthesis based, insightful, and inductive - R. Echtin,** ***Systems Architecting,*** **1991**
- **Engineering**
  - **Generally analysis-based, factual, logical, and deductive -** ***ibid.***

The Past

- Systems Engineering is a relatively new discipline
  - International Council On System Engineering (INCOSE) is only 10 years old.
- Traditionally focused on Requirements and Interface Documentation and (ultimately) Verification and Validation
  - some attempt at optimization of system design via trade studies (usually about a single point design)
  - frequently combined with System Architecting

The System Engineering Process



CONSTRAINTS

- 313 Project Systems Engineering Procedure
- Institutional Standards, Guidelines & Procedures

INPUTS

- Mission & Systems Design Commitment
- Project Goals & Objectives
- Level 1 Requirements
- Science Requirements
- Project Guidelines and Constraints
  - -Project Organization
  - -Single Point Failure Policies
  - -Mission Success Criteria/Priorities
  - -Schedules
  - -Resource Allocations
  - -Project Implementation Plan

Project Engineering Activities

- Develop Project Requirements, Policies & Guidelines
- Define Project Architecture
- Design Project
- Define and Control Interfaces
- Allocate, Track & Control Technical Resources
- Perform Technical Analyses
- Verify Project Design vs Requirements
- Validate Project Design
- Manage and Control Project Risk
- Manage Project Communication & Documentation
- Ensure Review of Project Design
- Manage & Control Project Configuration

OUTPUTS

- Project System Architecture & Design descriptions
- Level "2" Requirements
- Requirements Allocated to Level "3"
- Project System Trade Study Results
- Level "2" Interface Agreements, Listings & Descriptions
- Project System Performance Req'ts
- PS Resource Estimates
- Risk & Margin Assessments
- Project V&V Requirements
- PS Development Plans
- Etc.

RESOURCES

- DNP processes & customer support
- Project System Engineering Course Materials
- DOORS
- Section 313 Reference Library

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The Past, continued

From JPL SE Course 1994

- **Design Teams**
- **Mission Trade Studies**
- **System Contracting**
- **Design to Cost**
- **System Definition**
- **Requirements Definition**
- **Systems Analysis**
- **System Architecture**
- **Design Trade Studies**
- **Technical Margin Management**
- **Detailed Interface Definition**
- **System Reliability**
- **Design Issue Resolution**
- **Integration and Test**
- **PFR Support**
- **Operations Support**
- **SE for small spacecraft**

The Present

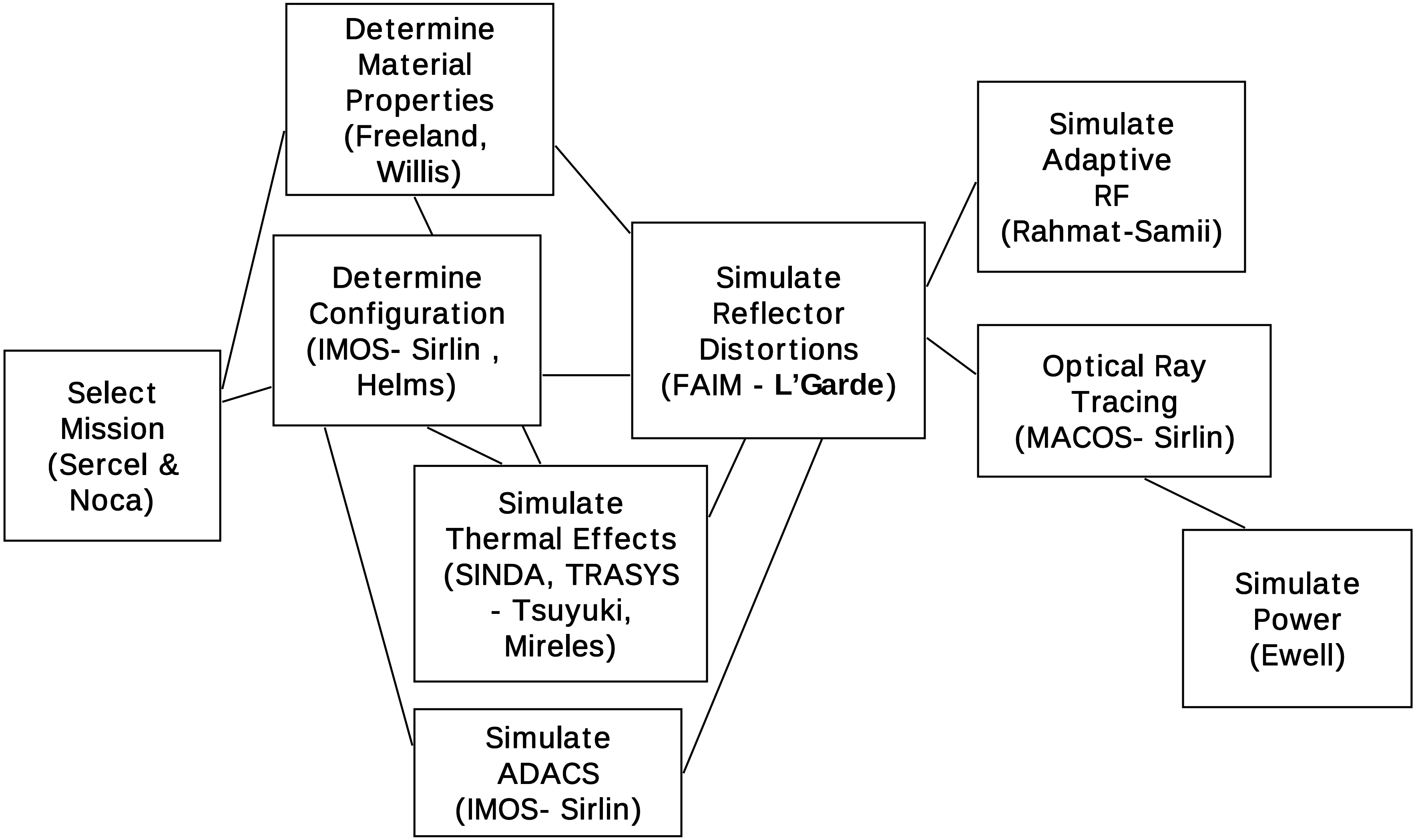
- **Faster Better Cheaper = Smaller**
- **More tools, more data, less time**
- **Concurrent engineering processes**
- **Collaborative engineering processes**
- **COTS Capability driven design**
  - **from large standard architectural elements to reusable components**
- **Risk as an element of trade studies**
- **Greater focus on handling exceptions**
- **Technology insertion**

Tools and Concurrent Engineering

- Worst case analysis (point design)
- Model based design to capture dynamic system behavior
  - Generic modeling tools or discipline specific
  - COTS and custom built
- Requires operational scenario
- Loosely coupled using generic data base and interfaces
- Tightly coupled using standard data formats
  - at increasing levels of fidelity and precision

Analysis Data Flow Example

Power Antenna


Determine Material Properties (Freeland, Willis)
Select Mission (Sercel & Noca)
Determine Configuration (IMOS- Sirlin , Helms)
Simulate Reflector Distortions (FAIM - L'Garde)
Simulate Adaptive RF (Rahmat-Samii)
Optical Ray Tracing (MACOS- Sirlin)
Simulate Thermal Effects (SINDA, TRASYS - Tsuyuki, Mireles)
Simulate Power (Ewell)
Simulate ADACS (IMOS- Sirlin)

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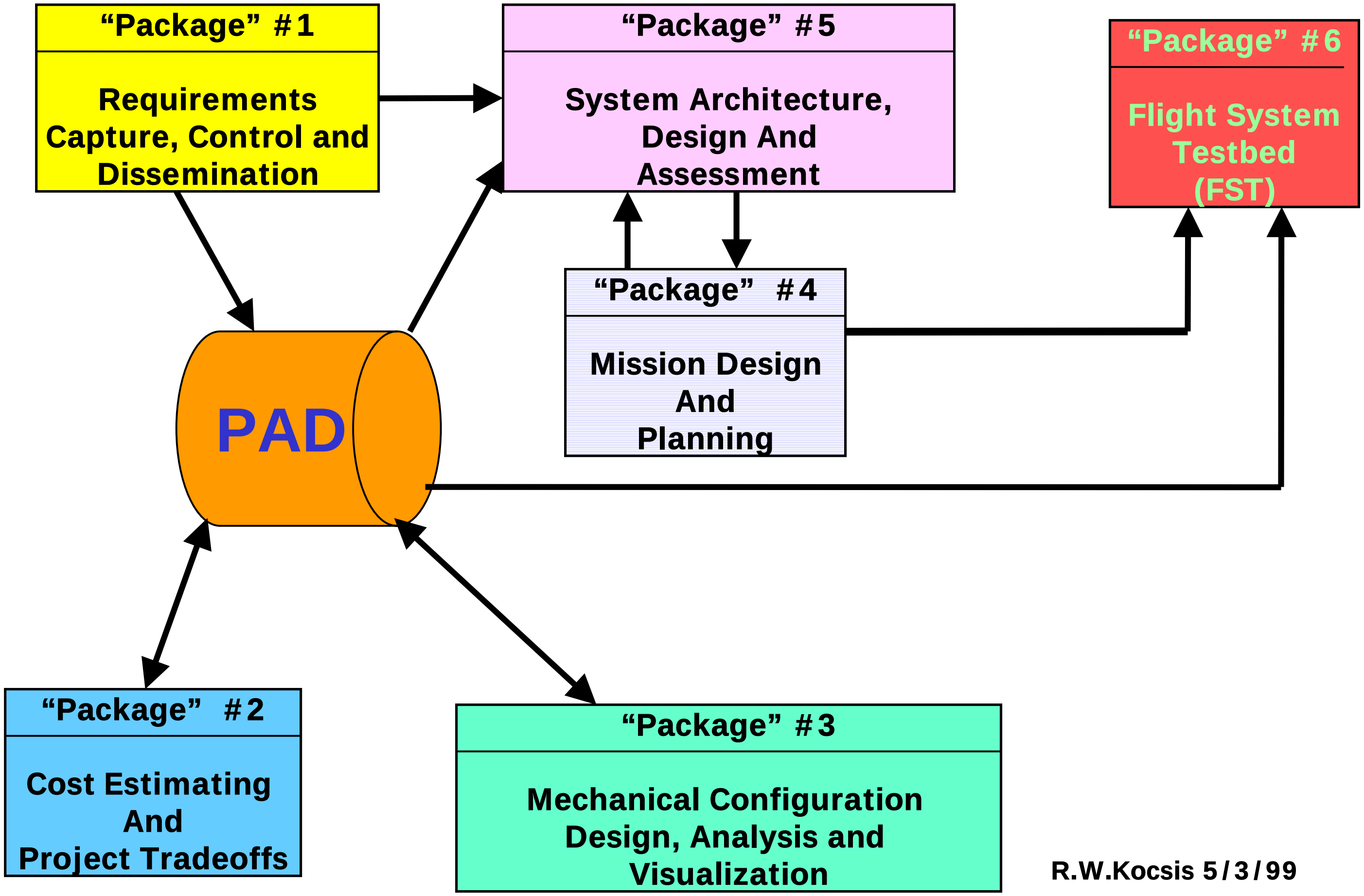
Integration with Database



“Package” #1

Requirements Capture, Control and Dissemination

“Package” #5

System Architecture, Design And Assessment

“Package” #6

Flight System Testbed (FST)

“Package” #4

Mission Design And Planning

PAD

“Package” #2

Cost Estimating And Project Tradeoffs

“Package” #3

Mechanical Configuration Design, Analysis and Visualization

R.W.Kocsis 5/3/99

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Risk Management

- **What is severity of the [negative] consequences of specific failures?**
- **What is the likelihood [probability] of specific failures?**
- **The combination of the above is the risk related to a specific failure**
  - **usually treated semi-quantively (binned)**
  - **unacceptable risks must be addressed in the design and operations**
- **Reviewed and status'd just like any other critical resource**

Exception Handling

- **The system engineer is [usually] the first to know if the overall system design is in trouble**
- **Margin management = critical system resource allocation and management**
  - **mass and power, radiation dosage, valves, etc.**
  - **not just the value at a point in time, but includes design value trajectory extrapolation over time**
- **Four R’s**
  - **Recover and Reallocate: can be done multiple times without serious consequences**
  - **ReDesign: depends on the extent of the redesign**
  - **ReScope: requires customer approval**

Technology Insertion

- Short development cycles means technology cannot be developed as part of the project
- Technology development is inherently risky
  - in terms of both cost, schedule, and performance
- No spacecraft development manager wants to depend on someone outside of the organization to deliver the right stuff in a timely fashion
- Actually comes down to a trade of cost, benefit, and risk

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The Future

- **Integrated Modeling and Analysis**
  - **libraries of high fidelity component and subsystem models**
  - **allowing for faster iterations on design concepts**
  - **systems requirements to design to system test data flow**
- **Artificial Intelligence for global optimization of trade spaces, however**
  - **design models are inherently non-linear**
  - **iterating non-linear systems can easily result in chaotic behavior**
    - **will require development of mitigating techniques**

A Few Conclusions

- **System engineers are increasingly dependent on their people skills**
  - **communication *and* teamwork**
- **Increasing automation will not change that**
  - **except to give SE's more time to work the people issues**
- **A new job**
  - **making sure all the automated models are in sync with reality**
- **An old job**
  - **understanding the disciplines well enough at both an intuitive and explicit level to spot inconsistencies and miscommunications**